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A METHOD FOR EVALUATING

KC-135 AVIONICS CONFIGURATIONS

THESIS

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A METHOD FOR EVALUATING KC-135 AVIONICS CONFIGURATIONS,

9 Masters THESIS,

Presented to the faculty of the School of Engineering

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Preface

This thesis is the result of research done to determine if the Avionics Evaluation Program (AEP), a Monte Carlo simulation model, could be used to assess alternate avionic systems for the KC-135 aircraft. The impact of improved navigation reliability and accuracy on the KC-135 mission success rate was the primary area of investigation during the research. Alternate avionic suites were input into the AEP model and the results were compared with the results of the baseline simulation. To aid the reader, a glossary of acronyms used in this thesis can be found in Appendix A.

I hope that this research will be helpful to the people who are currently involved in the KC-135 Avionics Modernization Program and that it has been of some help in improving the AEP model.

I would like to thank my sponsor, Ms. Diane Summers, Technical Manager of the Systems Evaluation Group (AFAL/AAA-3), who got me interested in this thesis topic, and my advisor, Major Kenneth Melendez, who gave me continued motivation and advice during my research. Special thanks are also due to Captain Kenneth Almquist of AAA-3 for his thorough knowledge of the AEP and his help in applying the AEP to my thesis problem.

The views and conclusions in this thesis are solely my own and I assume full responsibility for any errors or omissions.

Joel R. Jerabek

Contents

Contents (Continued)

List of Figures

List of Tables

ABSTRACT

The KC/C-135 Avionics Modernization Program is currently tasked with determining the feasibility of replacing the KC/C-135 navigator with cost-effective avionics systems. The Avionics Evaluation Program (AEP) is a computer model that has been built to evaluate the mission impact caused by alternate avionics hardware configurations. Although the AEP was designed to model tactical aircraft missions, this thesis examines whether it could be applied to the strategic mission of the KC-135.

Aircraft performance data, hardware reliability data, and abort logic criteria were input into the model. A baseline simulation was conducted using the current KC-135 configuration. Two additional configurations, single inertial navigation system (INS) with a navigator and dual INS without a navigator, were selected and simulations conducted. These simulations were conducted with both peacetime and wartime mission scenarios.

An analysis of the AEP output data revealed that the addition of a single INS produced a significant improvement in navigational accuracy and that by replacing the navigator with a second INS, navigational accuracy could be maintained without a change in the mission success rate. The baseline established by this thesis is available for future use in evaluating other avionics configurations for the KC-135.

A METHOD FOR EVALUATING
KC-135 AVIONICS CONFIGURATIONS

I. Introduction

The Air Force is currently in the process of improving the performance and extending the life of the KC/C-135 fleet. An area of particular interest at this time is the modernization of KC/C-135 avionics equipment.

The overall objective of the KC/C-135 Avionics Modernization Program is to determine whether it is feasible for a two-crewmember (pilot and copilot) flight-deck to complete all KC/C-135 mission requirements with no compromise to either mission performance or aircraft operational safety by replacing the navigator with cost effective avionics systems. The KC/C-135 Avionics Modernization Program will concentrate on the avionics equipment necessary to: (1) reduce crew size, (2) reduce operating and maintenance costs, and (3) improve navigation systems (Ref 1:1.1).

Background

The required operational capability (ROC) that was stated in SAC ROC 5-74, dated 22 March 1974, and validated by Hq USAF, directed a KC/C-135 navigation system modernization effort to allow KC/C-135 operation in the trans-oceanic track system within the navigational tolerances established by the International Civil Aeronautical Organization and the Federal Aviation Administration. It was concluded that a single inertial navigation system (INS) and a new doppler system were needed to meet this requirement. A common strategic doppler system (common to the KC/C-135 and the B-52) has been developed and the Delco Carousel-IV INS has been selected to fulfill this requirement. An amendment to the ROC, dated 25 February 1977, stated a requirement for dual INS's in order to eliminate the navigator crewmember position (Ref 1:1.2.2). This amendment has initiated the KC/C-135 Avionics Modernization Program.

The KC/C-135 Avionics Modernization Program was preceded by two KC-135 crew reduction tests, Giant Change and Giant Boom, that were conducted by the Strategic Air Command. Both of these flight tests involved the installation of two Carousel-IV INS's in a KC-135 to eliminate the navigator's duties. Giant Change identified some phases of two crewmember tanker operations that required in excess of 100% crew effort to accomplish the required tasks within acceptable safety standard. Giant Boom concluded that the addition of a Flight Systems Operator reducod crewmember overload conditions during emergencies and critical phases of flight, and at no time did pilot/copilot overload conditions constitute a discernable safety problem (Ref 1:1.2.1).

The KC/C-135 Avionics Modernization Program is currently in the system definition phase. This phase combines mission analysis, system definition, and crew station evaluation studies to determine the crew system control and display requirements for a two-crewmember flight deck. The product of this phase will be the initial definition of criteria for crew systems and a detailed description of the crew tasks that must be performed to complete a mission. Phases I and II will follow the system definition phase and they will consist of system validation through flight simulation and flight test, respectively.

Problem Statement

During the KC/C-135 Avionics Modernization Program, many different avionics configurations will be proposed. Each of these configurations needs to be objectively assessed for mission effectiveness on the KC/C-135 aircraft before an effective choice can be made.

Objectives of the Study

The primary objective of this effort is to determine if the Avionics Evaluation Program computer model can be used as a quantitative method to comparatively evaluate various KC/C-135 avionics configurations in terms of their potential reliability and effectiveness in a realistic mission environment. If the AEP can be used in this manner, this thesis will provide a baseline for future use during the KC/C-135 Avionics Modernization Program.

A secondary objective is to produce a list of expected equipment failures that can be used during the flight simulation phase to construct realistic mission scenarios that would include typical system failures.

Assumption

This thesis is based on the assumption that the KC-135 can safely complete its tanker mission by replacing the navigator with cost effective avionics systems.

Hypothesis

The Avionics Evaluation Program (see Methodology) can be used to objectively assess alternate avionic system design/concepts for the KC-135 aircraft, in terms of mission effectiveness, in a realistic mission environment.

Scope

This study will deal only with system reliability and will consider neither system costs nor maintainability. The study will consider only the mission and equipment of the KC/135A aircraft, since they represent the majority of aircraft in the KC/C-135 fleet.

This paper will first describe what the Avionics Evaluation Program is and how it was used for this study. Next, an evaluation of the model will be made through verification, validation, and analysis of the output data. Finally, a summary, with conclusions and recommendations will be given.

II. Methodology

The primary tool used in this study will be the Avionics Evaluation Program Air-to-Ground Mission Analysis Model, hereafter referred to as the AEP. This model was developed by the Battelle Columbus Laboratories for the Air Force Avionics Laboratory (AFAL) and is documented in AFAL-TR-76-196.

The AEP is a Monte Carlo simulation of a flight of aircraft (up to four) through a specified number of days of operation. Functions considered in this model include ground maintenance, communication, navigation, refueling, target acquisition, and weapon delivery. The program operates as follows:

(1) The user provides data which: (a) defines the flight profile, (b) lists the hardware makeup (all aircraft identically equipped, and the associated aircraft performance), and (c) defines the functions to be used for the simulation.

(2) The program makes a deterministic evaluation of the mission. As part of the evaluation, the aircraft equations of motion are integrated to determine the nominal time history of the flight. The aircraft states are stored as a function of time for use during the Monte Carlo evaluation. This part of the program is also referred to as the nominal portion of the simulation.

(3) A Monte Carlo simulation is conducted. A single Monte Carlo trial is represented by simulating the scheduled flight operations for a specific number of days. The events that occur during a mission depend on random draws from probability distributions described by function performance data and hardware reliability. Numerous trials are simulated to estimate: (a) mission success, (b) mission aborts, and (c) aircraft losses (Ref 2:3).

The AEP provides a means for assessing the mission impact caused by different avionic hardware configurations and allows the user to obtain a quantitative view of the importance and interaction of the hardware characteristics (Ref 2:5).

Flight Profile

In order to begin this study, a typical KC-135 mission had to be selected. The Air Force Flight Dynamics Laboratory, with the help of Strategic Air Command, has developed three "representative" tanker mission scenarios for use in their Tanker Avionics/Aircrew Complement Evaluation (TAACE). The first TAACE mission scenario consists of a two ship cell of KC-135's that takeoff from Loring AFB, Maine, rendezvous with a flight of fighter aircraft and escorts and refuels them on their deployment to the United Kingdom, and landing at RAF Mildenhall, United Kingdom (Figure 1). This scenario was chosen to represent the peacetime tanker mission for the AEP simulation because mission success depends heavily upon

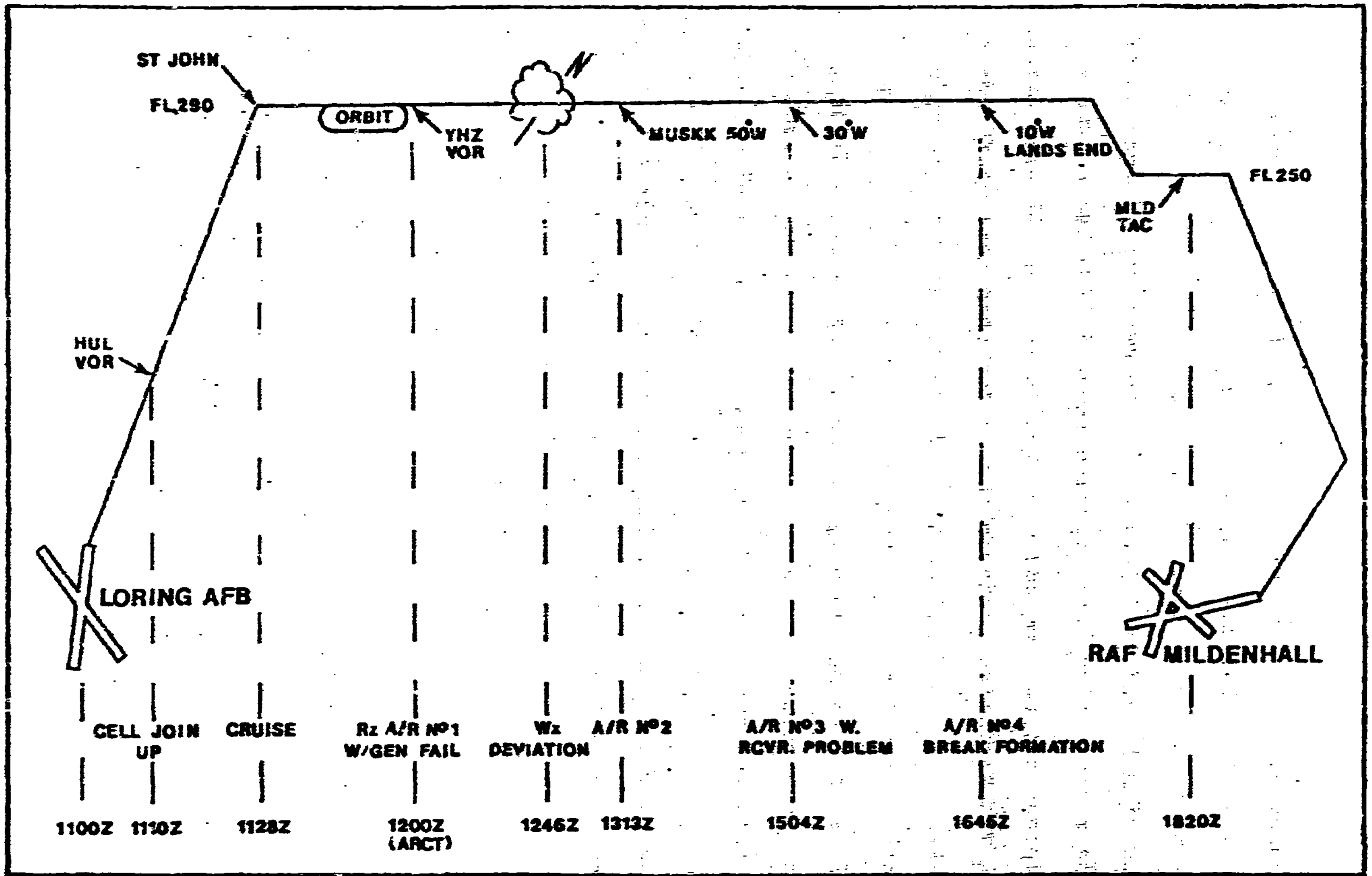

Figure 1. Loring Tanker Task Force Mission Profile (Source: AFFDL/FGR)

the accuracy and reliability of the aircraft's navigation equipment. The second and third TAACE mission scenarios represent tanker missions under Emergency War Orders (EWO) or wartime conditions. These scenarios involve the refueling of B-52 and FB-111 aircraft, respectively. Because of their similarity, only mission scenario two was chosen to represent a wartime mission profile for the AEP simulation. In TAACE mission scenario two, a two ship cell of KC-135's takeoff from RAF Mildenhall and proceed directly to an over-water, high-latitude rendezvous with two B-52's. Because of weather along the original refueling track, a diversion to a new refueling track is made and a rendezvous with the B-52's is completed. The tankers leave the receivers and make an emergency recovery at Bodo RNAFB, Norway (Figure 2). The various equipment failures and degraded operating modes depicted in these scenarios are output products of the AEP and were not input into the AEP simulation.

Once these scenarios had been chosen, they had to be put into the mission profile format used by the AEP. To simplify the mission profiles, all missions fly a straight track from takeoff to landing. This assumption should not affect the results of the simulation because most of a normal tanker mission consists of "straight and level" flying and the actual turns made during a real mission would be well within the aircrafts performance capabilities. The AEP flight profile is defined by a set of waypoints that describe the flight path. Waypoints need only be specified

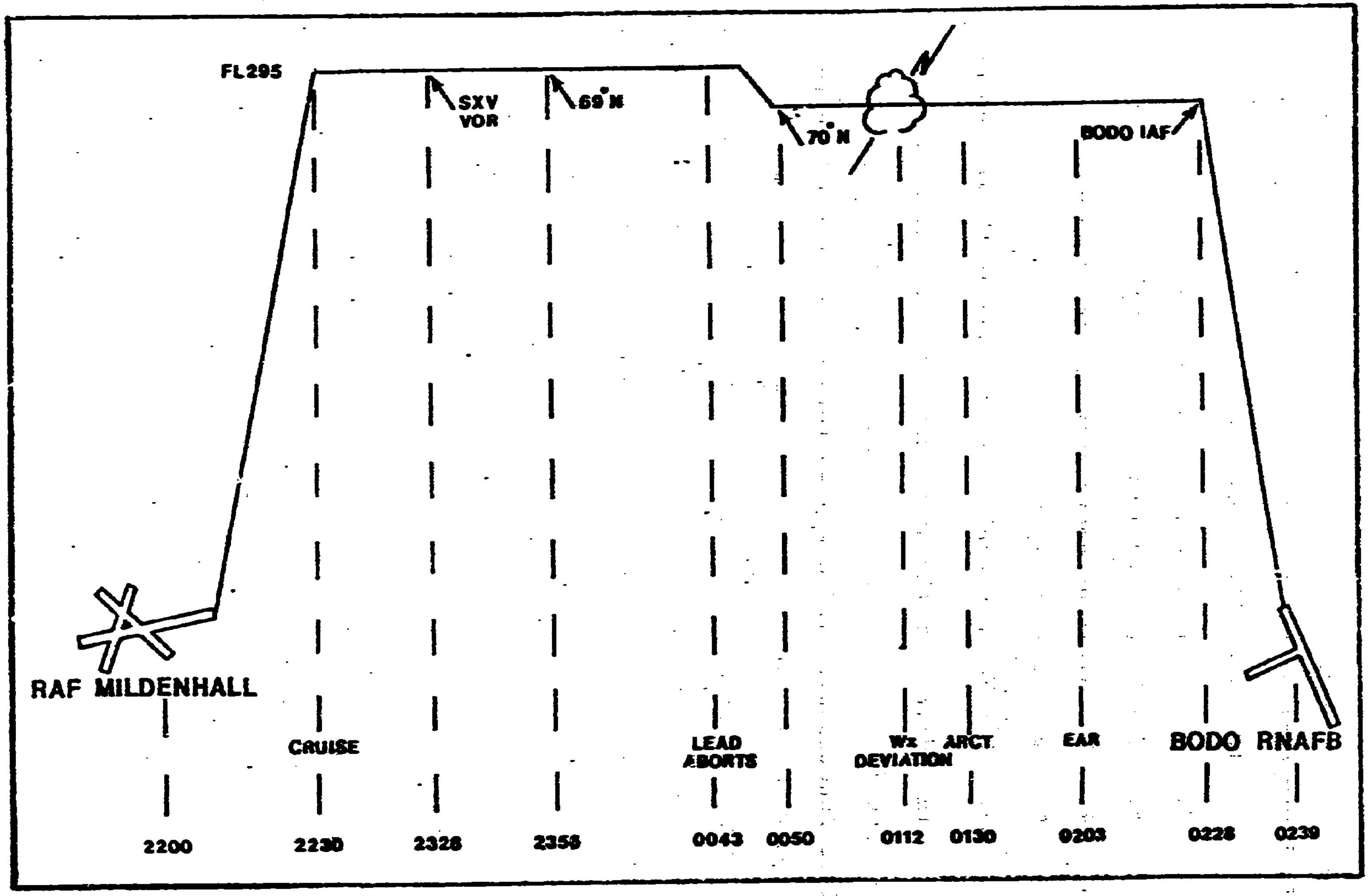

Figure 2. Mildenhall EWO Mission Profile (Source: AFFDL/FGR)

where some change in heading, velocity, or altitude occur. Each waypoint of the flight profile is defined by:

1. ID - Identification number
2. X - X distance from origin (NM)
3. Y - Y distance from origin (NM)
4. H - Altitude above mean sea level (feet)
5. V - Velocity in knots
6. B - Maximum bank angle allowed at this waypoint

In addition to the above data, the waypoints are used to specify the on and off times for the flight functions (see Functions). The user can turn on or turn off up to five functions at a single waypoint. Mode regression within a function to a less desired operating mode will not occur unless that function is turned on even though an equipment failure associated with that function has occurred. The ABP assumes that the equipment failure rate is the same whether a function is on or off since most aircraft equipment is left on for the entire mission. The on-off capability of the model allows the simulated mission to continue to the logical point the abort would have actually occurred, thus providing realistic exposure to additional equipment failures and the possible aircraft loss due to compound failures.

The flight profile includes the locations of targets which are used in the target-acquisition function to simulate radar identificc tion of receiver aircraft and severe weather. Up to five rargets can be defined by specifying their position with their X and Y distances (NM) from the origin. The flight profile data used in the AEP simulation is shown in Tables I and II.

Aircraft Equipment

As part of the input data, the user must list the aircraft equipment. Two terms, section and candidate, are used to describe hardware. These terms are defined as follows: (Ref 2:7).

> A section is a general category of hardware such as navigation or communications. In general, the first two digits of the standard Air Force Work Unit Code (WUC) defines a section.
>
> A candidate is a specific hardware item within a given section. For example, a candidate for a communication system might be an ARC-34 (UHF radio) or an ARC-58 (HF radio).

In selecting the equipment for the simulation, the user must determine the level of detail desired for each aircraft system. The critical systems considered for this study are listed in Appendix B. Non-avionic systems, such as the hydraulic system, are considered in the simulation so that improvements in mission success due to improved avionics equipment can be compared to the overall mission success rate. Most non-avionic systems are considered to be one piece of

Table I

Loring Tanker Task Force Flight Profile

ID	X	Y	H	U	BANK	ON		OFF	
1	0.0	0.0	0.0	185.0	0.0	302	661		
						702	3001		
2	168.0	0.0	29000.0	360.0	0.0	902			
3	274.0	0.0	29000.0	375.0	0.0	901	3002		
4	375.0	0.0	29000.0	405.0	0.0	702	303	7	
5	453.0	0.0	29000.0	470.0	0.0	302		9	3
								11	
6	735.0	0.0	29000.0	470.0	0.0	1101	3003		
7	939.0	0.0	29000.0	470.0	0.0	902		11	
8	947.0	0.0	29000.0	470.0	0.0	901	303	9	
9	1025.0	0.0	29000.0	470.0	0.0	302		9	3
10	1471.0	0.0	29000.0	470.0	0.0	302			
11	1808.0	0.0	29000.0	470.0	0.0	902			
12	1816.0	0.0	29000.0	470.0	0.0	901	303	9	
13	1894.0	0.0	29000.0	470.0	0.0	302		9	3
14	2411.0	0.0	29000.0	470.0	0.0	302			
15	2607.0	0.0	29000.0	470.0	0.0	901	303		
16	2685.0	0.0	29000.0	470.0	0.0	3004		9	3
17	2787.0	0.0	25000.0	450.0	0.0				
18	3000.0	0.0	25000.0	450.0	0.0	302			
19	3170.0	0.0	0.0	250.0	0.0			7	6
								3	

TARGET 1 LOCATION - X= 374.0 Y= 0.0
TARGET 2 LOCATION - X= 835.0 Y= 0.0

Table II

Mildenhall EWO Flight Profile

ID	X	Y	H	U	BANK	ON		OFF	
1	0.0	0.0	0.0	185.0	0.0	601	702		
						3001			
2	180.0	0.0	29500.0	360.0	0.0				
3	586.0	0.0	29500.0	420.0	0.0				
4	602.0	0.0	29500.0	420.0	0.0	3002			
5	931.0	0.0	29500.0	420.0	0.0				
6	980.0	0.0	28000.0	420.0	0.0	1101	3003		
7	1130.0	0.0	28000.0	420.0	0.0			11	
8	1134.0	0.0	28000.0	420.0	0.0	1101			
9	1260.0	0.0	28000.0	420.0	0.0	303		11	
10	1491.0	0.0	28000.0	420.0	0.0	3004		3	
11	1650.0	0.0	28000.0	420.0	0.0				
12	1820.0	0.0	0.0	200.0	0.0			6	7

TARGET 1 LOCATION - X= 1129.0 Y= 0.0
TARGET 2 LOCATION - X= 1230.0 Y= 0.0

equipment in the simulation, thus, these sections usually have only one candidate. Since the goal of this study is to determine the impact of avionics equipment on the overall mission success rate, avionics-related sections are looked at in more detail so that different candidates within a section can be changed to determine their impact on the mission success rate.

For each candidate in a section considered, the standard equipment data items shown in Table III must be established. Since this study has been limited to system reliability and will not address system cost or maintainability, only the mean time between failure and the number of redundant boxes for each candidate needed to be furnished.

TABLE III

STANDARD EQUIPMENT DATA ITEMS (Ref 2:8)

1.	MTBF	- True mean time between failures based on flight hours
2.	MTBMA	- Mean time between unscheduled maintenance actions
3.	OFR	- Operational hours per flight hour
4.	P_V	- Vulnerability
5.	N_R	- Number of redundant boxes
6.	MTTR	- Mean time to repair
7.	P_R	- Probability the box will be replaced
8.	P_A	- Probability replacement box is available
9.	P_u	- Probability of undetected failure
10.	P_F	- Probability of false failure
11.	A_c	- Acquisition cost
12.	UM_c	- Cost per unscheduled maintenance action

The reliability data (Appendix B) used in this study was taken from a source titled "Maintenance Actions, Manhours, and Aborts by Work Unit Code". This data is provided by the Air Force Logistics Command for almost all Air Force aircraft, missiles, trainers and simulators, and ground equipment. This data is updated monthly and lists specific data for the previous six months. Most equipment data necessary for this simulation was available from this data source. The mean time between failure (MTBF) is computed for each work unit code unless no failures have been reported for that WUC for any three consecutive months during the last six months. For each monthly MTBF computation, a three-month accumulation of failures and operating time (flying time) is used. The following formula is employed:

$$MTBF = \frac{\text{Operating time X Use factor X QPA}}{\text{Number of Failures}}$$

where:

Use factor = ratio of unit operating time to flying time (normally 1.0).

QPA = number of identical items reportable under one work unit code.

The KC-135A Aircraft Flight Manual (Ref:3) and the author's experience, with over 1000 hours of flying time as a KC-135 pilot, were used to determine which aircraft sections and candidates would be considered as mission essential for this simulation. In general, the minimum equipment required for a normal peacetime takeoff was used for the peacetime simulation. During the EWO simulation, the equipment required for takeoff is reduced to the minimum required to get the aircraft airborne. Most non-avionic sections were viewed as a single piece of equipment and the MTBF represented the combined failure rate for all hardware within that section. The avionics sections (instruments, communications, and navigation) were looked at in greater detail so that the impact of those candidates on mission success could be evaluated. The sections and candidates selected for use in the simulation are shown in Table IV.

Aircraft Performance

The deterministic evaluation of the mission requires that the performance of the aircraft be specified. To accomplish this, four additional standard equipment data items are required to define the airframe candidates. These data items are as follows:

13. Weight of Airframe (lbs) 165,000
14. External Fuel (lbs) 0
15. Internal Fuel (lbs) 156,000/185,000
16. Aircraft Type (1 - 10) 9

The first three items are used to vary the gross weight of the aircraft for the simulation. To simulate different aircraft performance, the internal fuel was varied from 156,000 lbs to 185,000 lbs to represent the takeoff fuel loads for peacetime and EWO missions, respectively. Item 16,

TABLE IV

KC-135A Equipment List

EQUIPMENT CURRENTLY BEING USED

AIRFRAME
- 1 KC-135/A ACFT

LANDING GEAR
- 1 LANDING GEAR
- 2 EMERGENCY LANDING GEAR

FLIGHT CONTROLS
- 1 FLIGHT CONTROLS

PROPULSION SYSTEM
- 1 J-57 ENGINE NO.1
- 2 J-57 ENGINE NO.2
- 3 J-57 ENGINE NO.3
- 4 J-57 ENGINE NO.4
- 5 ENGINE CONTROLS
- 6 WATER INJECTION SYSTEM

AIR-CONDITIONING, PRESSURIZATION
- 1 ENVIRONMENTAL CONTROL

ELECTRICAL POWER SUPPLY
- 1 ELECTRICAL SYSTEM
- 2 COPILOTS INSTRUMENT POWER

LIGHTING SYSTEMS
- 1 ACFT LIGHTING

HYDRAULIC AND PNEUMATIC POWER SUPPLY
- 1 HYDRAULIC SYSTEM

FUEL SYSTEM
- 1 FUEL SYSTEM
- 2 AIR REFUELING SYSTEM

INSTRUMENTS
- 1 PILOTS FLIGHT DIRECTOR
- 2 COPILOTS FLIGHT DIRECTOR
- 3 PILOTS INSTRUMENTS
- 4 COPILOTS INSTRUMENTS
- 5 PILOTS ALTIMETER
- 6 COPILOTS ALTIMETER
- 7 PERISCOPIC SEXTANT
- 8 ENGINE INSTRUMENTS
- 9 FUEL QUANTITY SYSTEM
- 10 REFUELING INSTRUMENTS

AUTOPILOT
- 1 N-1 COMPASS SYSTEM
- 2 J-4 COMPASS SYSTEM

VHF COMMUNICATIONS
- 1 HF RADIO ARC-58

UHF COMMUNICATIONS
- 1 UHF RADIO NO.1 ARC-34
- 2 UHF RADIO NO.2 ARC-34

IFF
- 1 IFF/SIF SYSTEM

RADIO NAVIGATION
- 1 VOR/LOC RECEIVER
- 2 TACAN RECEIVER

RADAR NAVIGATION
- 1 SEARCH RADAR APN-59
- 2 BEACON RADAR APN-69
- 3 DOPPLER RADAR SYSTEM
- 4 NAV.COMPUTER ASN-7
- 5 CAROUSEL IV INS 1

Aircraft Type, is used to retrieve data stored as a permanent file in the FASTAC Air-to-Air model. Since the KC-135 had not previously been used in this air-to-air model, its performance data had to be obtained and stored. The performance data and the format required by the FASTAC model are shown in Table V. This data is used during the deterministic evaluation to determine the nominal time history of the flight and can be found in Appendix C.

Functions, Subfunctions, Modes, and States

The concept of functions, subfunctions, modes, and states used in the AEP is fundamental to the understanding of the model. Functions are the operations or actions performed during the simulation. Subfunctions represent alternate options for performing a particular function. Table VI lists the functions and subfunctions, along with their associated data, that were used for this simulation. Only those functions and subfunctions that have data requirements or were used in the simulation are chosen.

Several operating modes (primary and backup modes) are possible for each subfunction, and for this reason, some of the subfunctions listed on Table VI show multiple data. This represents data for different modes, with mode 1 being on the left. The concept of modes is simple for a one aircraft simulation. In that case, there is a single suite of hardware and performance data associated with each mode that is defined for a subfunction. The user sets up the problem such that the first mode represents the best performance

TABLE V. FASTAC INPUT DATA FOR DEFINING NEW AIRCRAFT

Variable	Units	Format
Name		8A10
Weight	lb	4F10.0
Reference Area	sq. ft.	4F10.0
Drag Brake Coefficient		4F10.0
Normal Acceleration	g's	4F10.0
- - - Maximum Lift Coefficient Versus Mach - - -		
Mach Numbers		13F6.0
Maximum Lift Coefficients		13F6.0
- - - Drag Coefficient Versus Lift Coefficient and Mach - - -		
Mach Numbers		13F4.0
Lift Coefficients		11F4.0
Drag Coefficients		Up to 13 cards, 11F4.0, scaled by 0.0001
- - - Engine Data Versus Altitude and Mach - - -		
Mach Numbers		
Altitudes	ft	
Afterburner Thrush	lb	Up to 13 cards, 6F9.0
Afterburner Fuel Flow	lb/hr	Up to 13 cards, 6F9.0
Military Thrust	lb	Up to 13 cards, 6F9.0
Military Fuel Flow	lb/hr	Up to 13 cards, 6F9.0
- - - Maximum Velocity Versus Altitude - - -		
Altitudes	ft	11F5.0
Maximum Mach Numbers		11F5.0
- - - Angle of Attack Versus Lift Coefficient and Mach - - -		
Mach Numbers		13F6.0
Lift Coefficients		11F6.0
Angle of Attack	deg	Up to 13 cards, 11F6.0

TABLE VI

FUNCTION/SUBFUNCTION DATA REQUIREMENTS

Function	Subfunction Name (number)	Data
FUEL	Fuel Loading (3.1)	
	a. Fueling rate (lb/min)	5000
	Fuel Usage (3.2)	
	a. Minimum fuel level (lb).	18,000/0
	Refueling (3.3)	
	a. Minimum Hook-up time (min)	10/20
	b. Maximum hook-up time (min)	10/20
	c. Refueling rate (lb/min). . . .	-1000/-6000
	d. Number of aircraft refueled simultaneously	1
FLIGHT	Launch (4.1)	
	a. Mean wait time (min)	30
	b. Standard deviation (min)	5
	Inflight Aircraft Abort (4.2)	
	Mission Abort (4.3)	
	Aircraft Loss (4.4)	
	Landing (4.5)	
MISSION	Schedule (5.1)	
	a. Earliest time to begin preflight (hr)	0900
	b. Earliest time to begin launch (hr)	1100
	c. Minimum time until next sortie (hr)	24
	d. Latest time to launch sortie (hr)	1200
	e. Maximum delay before cancel (hr)	1
	f. Number of days to simulate	1
FORMATION	Nominal Flight (6.1)	
	a. A/c 2 relative to a/c 1 (ft)-behind	5000
	b. A/c 2 relative to a/c 1 (ft)-right	3000
	c. A/c 2 relative to a/c 1 (ft)-above	500

TABLE VI (Continued)

FUNCTION/SUBFUNCTION DATA REQUIREMENTS

Function	Subfunction Name (number)	Data
NAVIGATION	Radio Aided Navigation (7.1)	
	a. Fixed position error (nm)	3.2/5.0
	b. Correlation time constant (min)	0
	Self-Contained Navigation (7.2)	
	a. Per unit time error growth rate (nm/hr).	.96/4.9/5.6/9.3/13.6
	b. Correlation time constant (min)	1.0/10.0
COMMUNI-CATIONS	Interflight (9.1)	
	External (9.2)	
TARGET AC-QUISITIONS	Display Acquisition (11.1)	
	a. Horizontal Width of Sensor Field of View	179.9
	b. Side Look Angle for Each Aircraft	0
	c. Table of Depression Angles	
	d. Cumulative Probability of Detection vs. Depression Angle	
	Visual Acquisition (11.2)	
	a. Horizontal Width of Sensor Field of View	179.9
	b. Side Look Angle for Each Aircraft	-45/45
	c. Table of Depression Angles	
	d. Cumulative Probability of Detection vs. Depression Angle	

and subsequent modes represent degraded performance. The introduction of multiple aircraft into the simulation complicates the problem as the modes must then apply to the entire flight of aircraft. The user defines mode regression criteria for the flight using subfunction states. A subfunction state defines the equipment status for each aircraft for that particular subfunction. Associated with each state is a suite of hardware selected from the list of candidates. State 1 represents the primary equipment state and subsequent states represent progressively degraded hardware states. Based on the definition of these states, Boolean AND/OR logic is used to define the criteria for each mode (Ref: 2:8-15). A diagram of the Function/Subfunction/Mode/State hierarchy is shown in Figure 3. To illustrate how this hierarchy is used in the simulation, these relationships for the communications function would be:

9. Communications (function 9 of AEP)

9.1 Interflight (subfunction 1 of function 9)

State	Equipment	(candidates required for each state)
1	63-1 63-2	(UHF radio No. 1 & 2
2	63-1	
3	63-2	

Modes	Description	Required States
1	Both Dual UHF	A1+B1
2	One Single UHF	A1+B2/A1+B3 A2+B1/A3+B1
3	Both Single UHF	A2+B2/A2+B3 A3+B2/A3+B3

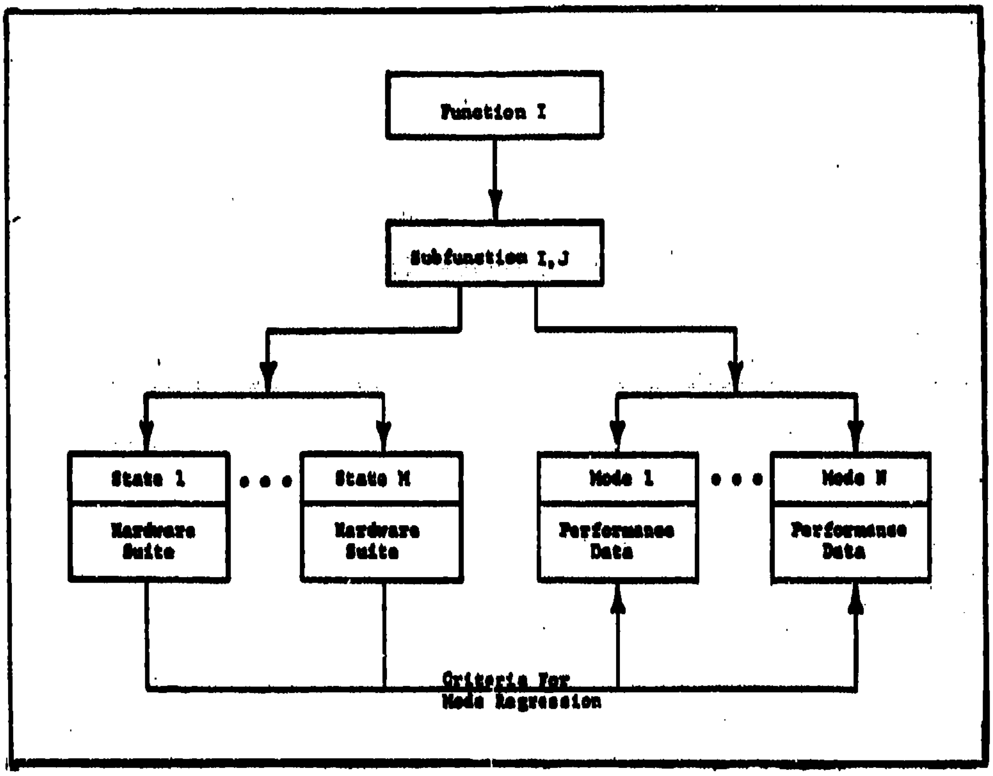

Figure 3. Function/Subfunction/Mode/State Hierarchy (Ref 2:15)

9.2 External (HF for overwater mission)

State	Equipment
1	62-1 (HF radio)

Mode	Required State
1	A1/B1

For interflight communications, aircraft A and B take-off in mode 1. If, for example, A loses 63-1 (No. 1 UHF radio fails), the state requirements for mode 1 can no longer be met and mode regression to mode 2 for interflight communications would occur. This would happen since A is now in state 3 and B remained in state 1 (A3+B1). If B were to lose 63-2 (UHF No. 2), regression to mode 3 would occur since A remained in state 3 and B is now in state 2 (A3+B2). If either A or B loses its remaining UHF radio, that aircraft would abort the next time subfunction 9.1 is turned on because there are no modes left to regress to. Similarly, for external communications, both aircraft are required to be in mode 1 for takeoff. If either aircraft A or B loses its 62-1 (HF radio), mode 1 is still retained since A1/B1 is an OR statement. If both aircraft lose their HF radios, then both aircraft would abort the mission (the next time subfunction 9.2 is turned on). It must be noted that if a subfunction is not turned on after an equipment failure, mode regression will not occur and, thus, an abort will not occur. The mode/state relationships for all subfunction used in this study can be found in Appendix D.

Functions to be Used

Some functions in the model are turned on/off by user input to the flight profile while others are controlled internally by the program. A list showing function control is shown in Table VII. Since scheduled maintenance, ordnance, weapon delivery functions, and weapons are internally controlled and will not be used for this simulation, it was necessary to ensure that all data related to these functions was set equal to zero. Likewise, the cost accumulation subfunction of the schedule function is not considered for this

TABLE VII. LIST OF INITIAL FUNCTION CALLS
(Ref 2:30)

Function	Control
1. Scheduled Maintenance	Internal
2. Ordnance	Internal
3. Fuel	
3-1. Loading	Internal
3-2. Usage	User turn on
3-3. Refueling	User turn on
4. Flight	Internal
5. Schedule	Internal
6. Formation	User turn on
7. Navigation	User turn on
8. Navigation Update	User turn on
9. Communication	User turn on
10. Survivability	User turn on
11. Target Acquisition	User turn on
12. Weapon Delivery	a. Turned on and activated internally by target detection or b. User turn on prior to target detection, then activated at detection
13. Target	Internal

simulation and all cost data was set equal to zero. The survivability function is not turned on during the simulation since survivability of the aircraft due to enemy ground fire is not a normal consideration for a tanker mission. The navigation update function is not used since the mode data used in the navigation function account for update capability. All remaining functions are used in the simulation and a brief description of each will be given.

Fuel. This function provides a means of managing the aircraft fuel requirements. Three subfunctions are available for fuel loading, fuel usage, and air-refueling. There are no direct nominal calculations for this function, however, the fuel flow rate during flight is one of the aircraft states that is provided by the aircraft flight simulation. An aircraft abort occurs if fuel monitoring or refueling states are not available. A mission abort occurs if no modes are available for air-refueling. The fuel loading subfunction is used to ensure that the aircraft fuel tanks are properly filled before each sortie. The fuel usage subfunction is called periodically during the simulation to monitor the fuel status and fuel flow. This subfunction aborts an aircraft if the remaining fuel is less than that required to complete the flight plus the required reserve. Figure 4 shows the control logic for fuel loading and usage. The air refueling subfunction allows the program to simulate onloading of fuel (if modeling a receiver aircraft) or off-

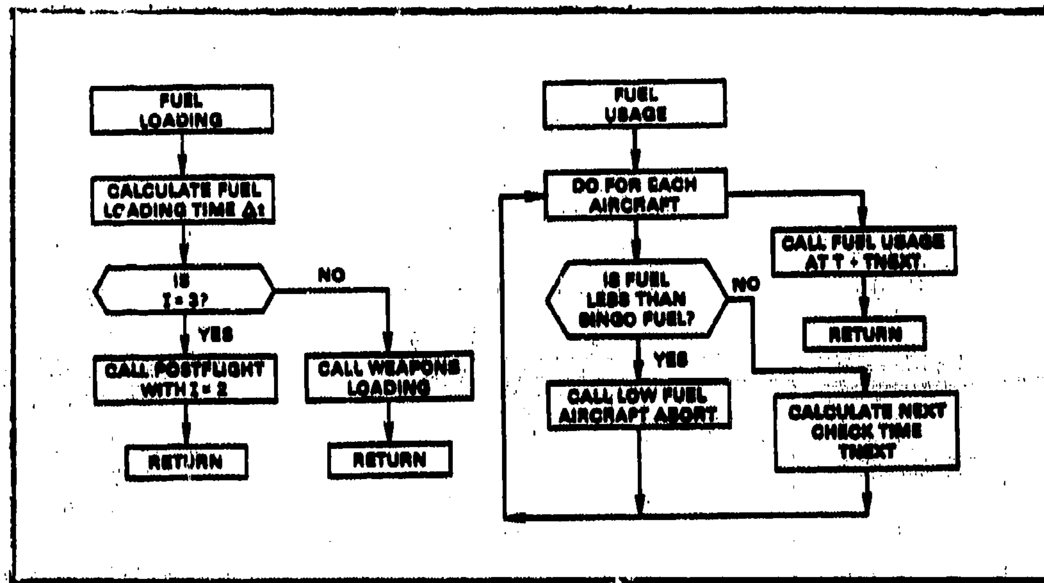

Figure 4. Fuel Loading and Usage Subfunctions (Ref 2:38)

loading of fuel (for this tanker simulation). Refueling occurs when the subfunction is turned on. The hookup time is determined from a uniform probability distribution specified by the input of a minimum and maximum hookup time. For this simulation, the minimum and maximum times were made equal in order to force a specified offload per refueling. Figure 5 shows the control logic used in the air refueling subfunction.

Flight. The flight function provides a means of specifying the equipment requirements for the various portions of the mission. Five subfunctions - launch, aircraft abort, mission abort, aircraft loss, and landing are available. Nominal calculations required by the flight function are performed during the aircraft flight simulation.

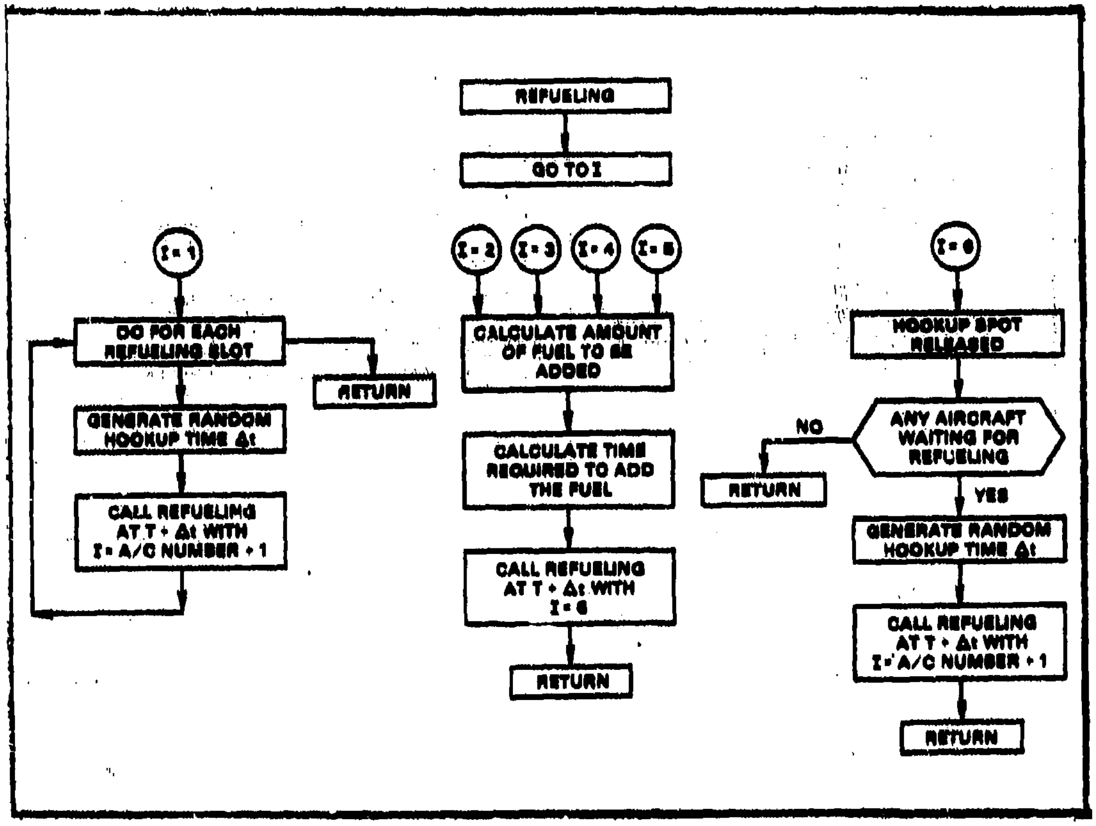

Figure 5. Refueling Subfunction
(Ref 2:39)

Figure 6 shows the control logic for the launch subfunction. A random sortie launch time is drawn from a log-normal distribution defined by the input data. This time represents the interval between engine start and takeoff. At takeoff, subfunctions 3.2 through 3.4 are turned on and 3.1 (launch) is turned off. A ground abort of the mission will occur if either an aircraft has no available equipment state or no mode requirement is satisfied.

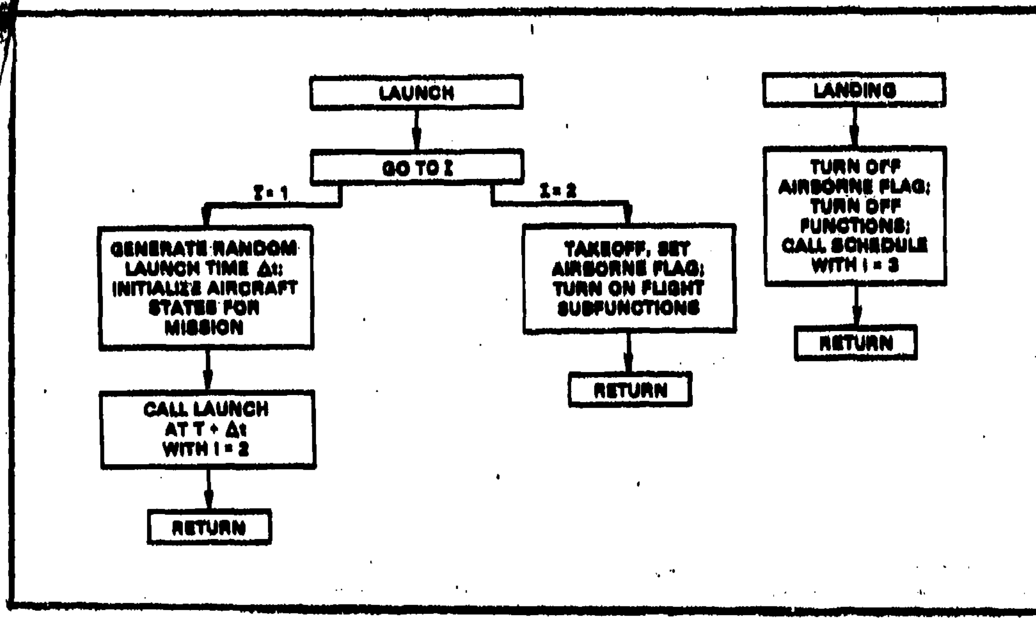

Figure 6. Launch and Landing Subfunctions (Ref 2:41)

The aircraft equipment states that are associated with the aircraft abort subfunction allow the determination of an aircraft abort during the simulation. For the aircraft abort subfunction, each aircraft must satisfy one of the OR conditions within the mode structure. This provides the capability to define the conditions for which the abort of one aircraft will cause the abort of another aircraft.

The mode/state requirements of the mission abort subfunction are used to define when the entire sortie must be aborted. If no modes are available for this subfunction, the entire flight of aircraft will abort the sortie.

The aircraft loss subfunction is used to define the minimum set of equipment necessary to keep the aircraft airborne. If no equipment state is available, the aircraft is lost or destroyed. Figure 6 shows the control logic for the landing subfunction. Control is transferred to the schedule routine upon landing. If no landing equipment state is available, the aircraft is considered lost.

Mission. This function provides a means of specifying the operations schedule and the cost of various portions of the simulated mission. The cost subfunction was not used since cost was not part of the problem. The schedule subfunction, using the input data, manages the engine start times for the individual sorties and is the overall mission scheduler for the nominal portion of the simulation.

Formation. This function is used to specify the position of the aircraft within the flight relative to the lead aircraft. The user specifies the distance right or left, behind, and above the leader for up to three additional aircraft.

Navigation. This function includes two subfunctions: radio aided navigation and self contained navigation. These subfunctions provide the capability of computing and considering navigation errors. Radio aided navigation considers fixed position error which is dependent upon aircraft equipment and ground station accuracies. Self contained navigation considers a per-unit-time navigation error rate where the total navigation error increases as the time from the last reliable navigation update fix increases. A mission abort occurs if the self contained navigation equipment for that subfunction fails. If the radio aided navigation fails, a switch to self contained navigation is attempted. If the switch is successful, the mission is continued; otherwise, a mission abort occurs. Figure 7 shows the control logic for these navigation subfunctions.

Communications. The communications function is used to assess the reliability of the communications equipment. The interflight subfunction considers communications between aircraft within the flight while the external communications subfunction considers communications from the flight to the ground. Since this simulation is mostly an overwater tanker mission, interflight communications is considered to be UHF communications while external communications is considered to be HF communications. Loss of all aircraft equipment states for interflight communications causes an aircraft abort. Loss of all modes for either subfunction causes a mission abort.

Target Acquisition. This function was used in this study to simulate the radar and/or visual identification of receiver aircraft during the air refueling rendezvous and severe weather encountered along the flight path. The display target acquisition subfunction is used to simulate radar identification while the visual target acquisition subfunction , as its name implies, is used to simulate visual detection. If no display acquisition modes are available, a switch to visual acquisition is made. Since the model can only search for targets that are located on

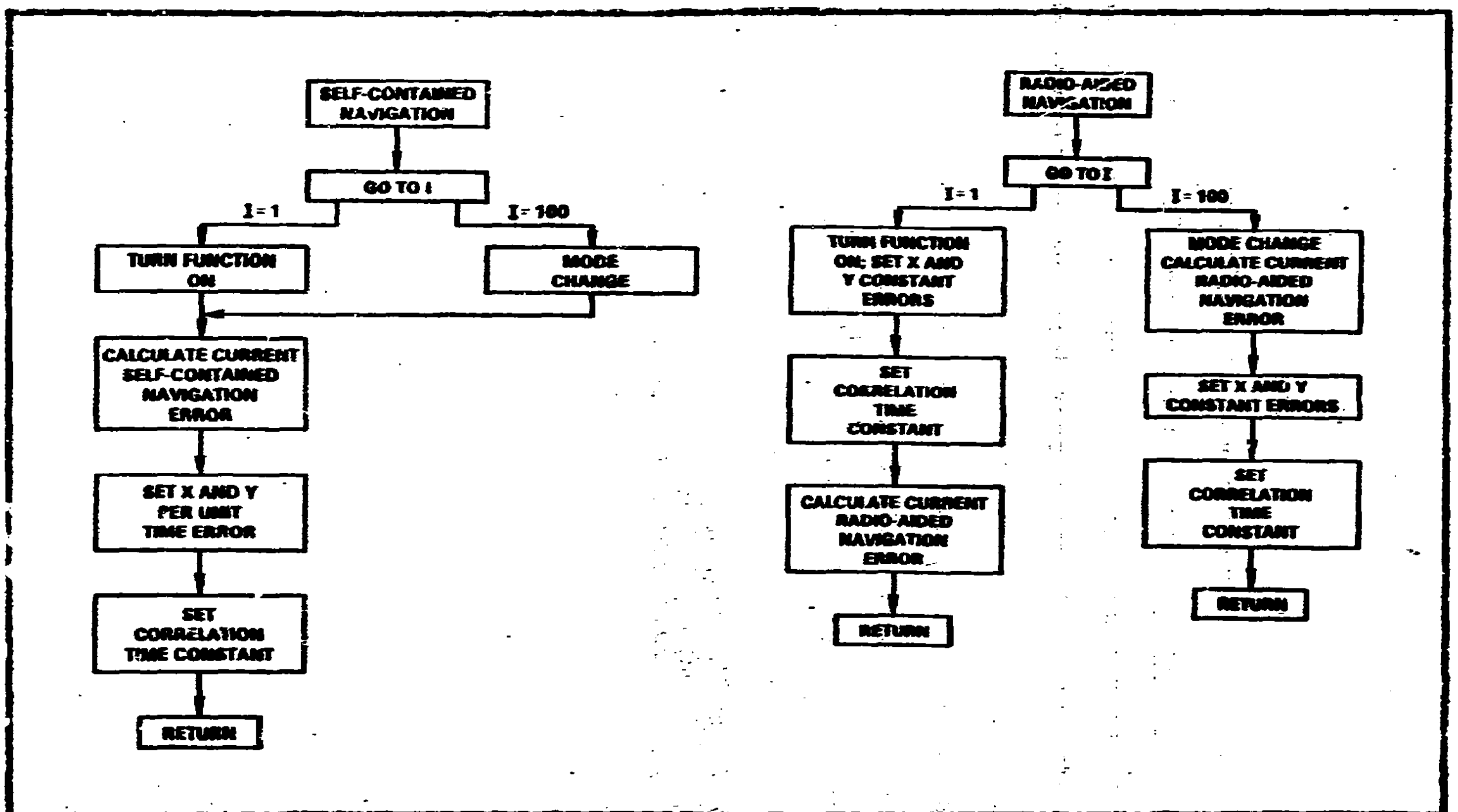

Figure 7. Navigation Subfunctions
(Ref 2:45, 46)

the ground surface, the targets projected ground position was used to determine if target acquisition occurred. The user supplies the parameters which determine the field of view (FOV). Figure 8 shows the geometry of the angles defining the FOV. Each mode of the acquisition subfunction provides data for these angles:

ϕ = depression to center of FOV

ψ = side angle to center of FOV

θ_v = vertical height of FOV

θ_h = horizontal width of FOV

When a target falls within the FOV, the depression angle is calculated and the probability of target detection, taken from the input table of detection probability versus depression angles, is used to determine if the target is acquired. There are no aircraft aborts due to loss of target acquisition equipment. A mission abort occurs only if all possible modes for both subfunction have failed. Since the visual target acquisition subfunction has no required equipment, a mission abort cannot be caused by loss of target acquisition equipment. Figure 9 shows the control logic used for the target acquisition subfunctions.

Navigation Error. Since a prime concern of this study is to determine the impact of navigational accuracy on mission success, a method to measure navigational accuracy was needed. The AEP, while internally calculating navigation error, had no method of outputting this data. To solve this problem,

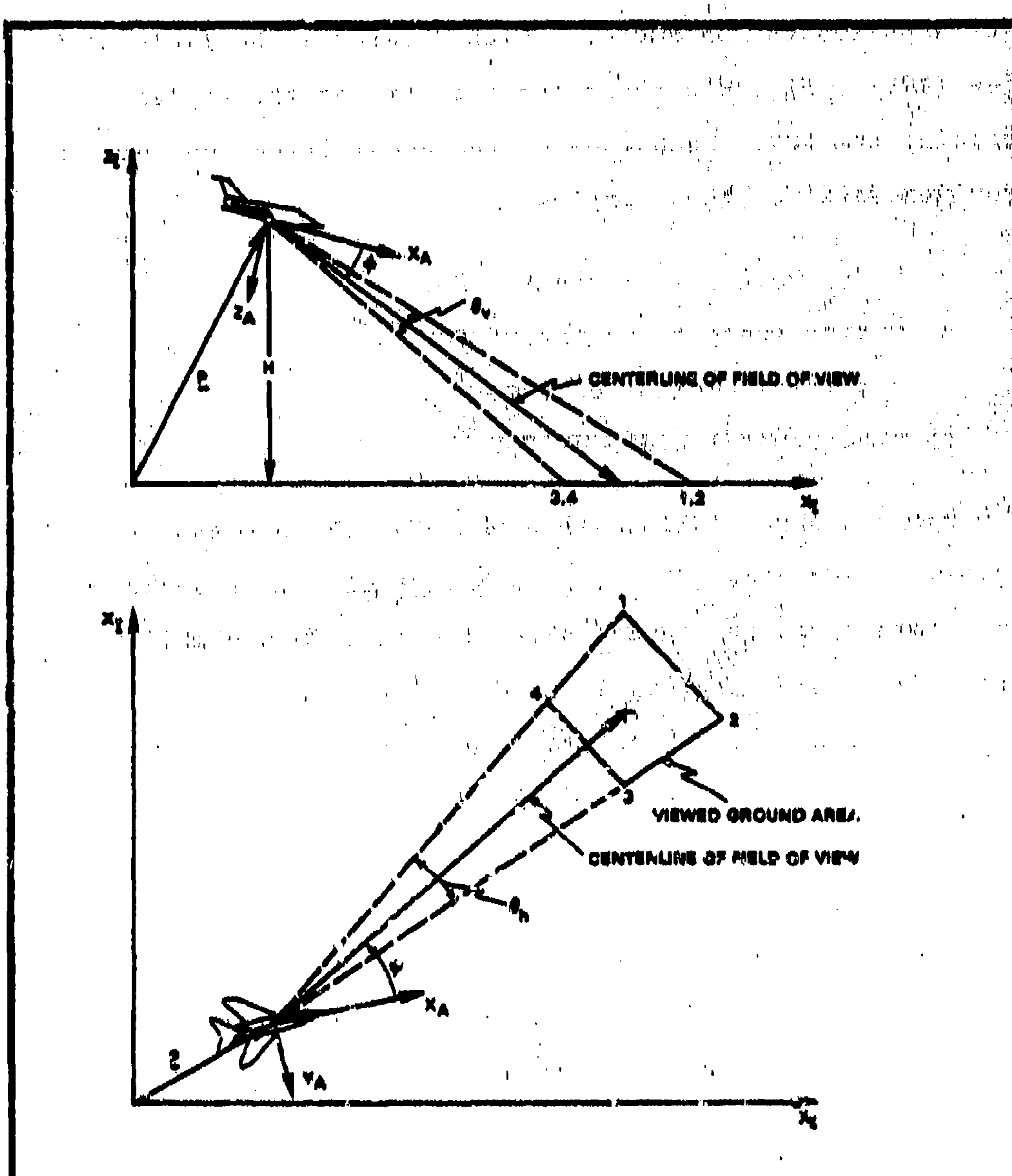

Figure 8. Field of View Geometry
(Ref 2:53)

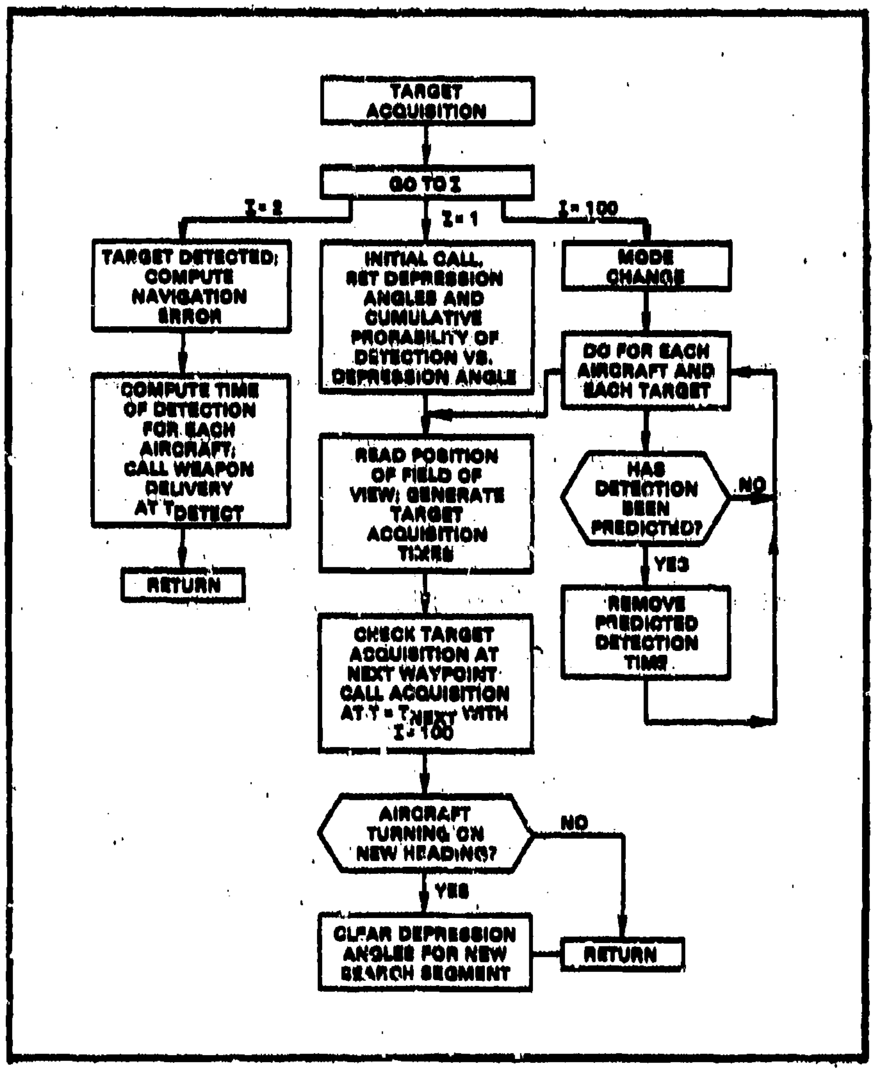

Figure 9. Target Acquisition Subfunction (Ref 2:56)

Battelle Columbus Laboratories was contacted. They were able to add a routine to the AEP which allows the user to sample the navigation error for up to five waypoints on the flight profile. This is accomplished by turning on navigation error subfunctions 30.1 through 30.5. The output of this subfunction represents the circular error from the planned waypoint coordinates to the simulated aircraft position. This output allows the user to evaluate the accuracy and reliability of various navigation hardware configurations.

Monte Carlo Evaluation

A Monte Carlo evaluation is performed after the mission flight path has been defined and all of the hardware, function, subfunction, state, and mode performance parameters have been defined. These parameters all define probability density functions which characterize performance. During each Monte Carlo run, random numbers are drawn from the appropriate density function to simulate actual performance. System failures are checked at short intervals on each run. A single density function reflecting the MTBF of all of the hardware elements is generated. An exponential failure rate is assumed for each of the subsystems, thus the failure rate for the total system is the sum of all the individual failure rates. A single random number is drawn at each interval to determine whether a failure occurred. If a failure did occur, another random number is drawn to determine which item failed. The distribution for this draw reflects the relative MTBF's of the equipment involved. Once a failure has occurred, each operating state/mode is checked to determine if the failed equipment is required. If a mode does require that equipment, regression occurs until a mode is found which has all operable equipment. If no mode can be found, the subfunction is inoperable and the program checks the appropriate function/subfunction subroutines to determine the impact of the loss of the subfunction. It may be that another subfunction can provide the necessary function or that the mission can be continued without the function. On the other hand, loss of the subfunction may dictate an aircraft or mission abort. Performance and failure events are accumulated for the numerous Monte Carlo runs and the results are listed in the programs output (Ref 5:21-22).

Interactive Graphics Processor

The AEP program is incorporated in an interactive graphics processor. The main objectives in providing an interactive capability are to:

1. Provide the user with an easier means of communicating with the computer.
2. Help verify that inputs are free from the common keypunch or typing mistakes.
3. Provide a data bank for storing and retrieving input data.
4. Provide sufficient instructions within the interactive software to avoid the need for consulting computer program manuals.
5. Provide graphical representation of input data and program results.

The AEP is a batch program, even though it is automatically executed from a remote interactive terminal. The input and output processors are used to communicate with the user for problem set-up and review of the output. A very important "Help" file and on-line user's manual are available to aid the user in communicating with the processors and associated programs (Ref 2:65-66).

III. Model Evaluation

A model should be created for a specific purpose, and its adequacy or validity evaluated only in terms of that purpose. To evaluate a model means to develop an acceptable level of confidence that inferences drawn from the performance of the model are correct and applicable to the real world system. The process of evaluating the AEP will be divided into three categories: (1) verification, to insure that the model behaves as it is supposed to; (2) validation, to test the agreement between the behavior of the model and that of the real world; and (3) analysis, which deals with the interpretation of the data generated by the model (Ref 4:208-210).

Verification

The first step in evaluating the AEP was to verify that the model has internal consistency. To accomplish this, the AEP was run with 3000 Monte Carlo trials of the Loring Tanker Task Force mission profile, using the KC-135 Baseline configuration. The simulated equipment failures generated by the model were compared to the expected equipment failures. To determine the expected equipment failures, the total simulated flight time was divided by the MTBF for each candidate considered in the baseline configuration. The baseline equipment candidates were then ranked from highest to lowest simulated failures. Table VIII lists the simulated and expected failures for all baseline candidates. To determine whether the simulated data could be considered

TABLE VIII

OBSERVED VERSUS EXPECTED EQUIPMENT FAILURES

	Name	Observed Failures (F_o)	Expected Failures (F_e)	$\frac{(F_o-F_e)^2}{F_e}$
1	Sextant	889	898.02	0.091
2	HF Radio (ARC-58)	256	278.22	1.775
3	VOR/LOC Receiver	127	111.84	2.055
4	UHF Radio #1 (ARC-34)	124	122.56	0.017
5	UHF Radio #2 (ARC-34)	119	122.56	0.103
6	Water Injection System	59	78.60	4.888
7	Pilots Altimeter	46	38.86	1.312
8	C/P Instrument Power	44	38.86	0.680
9	Search Radar (APN-59)	41	37.70	0.289
10	Landing Gear	35	33.32	0.085
11	C/P Altimeter	32	38.86	1.211
12	Beacon Radar (APN-69)	32	36.87	0.643
13	Nav. Computer (ASN-7)	30	34.10	0.493
14	Engine No. 2	29	23.62	1.225
15	Pilots Flight Director	29	19.43	4.714
16	C/P Flight Director	27	19.43	2.949
17	Compass System (J-4)	24	27.77	0.512
18	Electrical System	23	29.35	1.374
19	Doppler Radar	23	24.59	0.103
20	Engine Instruments	22	26.62	0.802
21	Fuel Quantity Gages	22	21.41	0.016

TABLE VIII (Continued)

	Name	Observed Failures (F_o)	Expected Failures (F_e)	$\frac{(F_o-F_e)^2}{F_e}$
22	Engine No. 1	22	23.62	0.111
23	Engine No. 4	22	23.62	0.111
24	Engine No. 3	18	23.62	1.337
25	Pilots Instruments	18	16.40	0.156
26	Compass System (N-1)	16	18.65	0.377
27	C/P Instruments	13	15.87	0.519
28	Tacan Set (ARC-72)	12	11.90	0.001
29	Flight Controls	12	10.71	0.155
30	Engine Controls	10	12.69	0.571
31	Hydraulic System	8	7.93	0.001
32	Fuel System	5	5.55	0.055
33	Environmental Controls	4	5.16	0.261
34	IFF/SIF System	3	5.55	1.172
35	Air Refueling System	5	3.67	
	Refueling Instruments	1	1.98	
	Aircraft Lighting	1	1.98	
	Airframe	1	0.45	
	Emergency Landing Gear	1	0.45	
		9	8.53	0.026

Σ 30.186

statistically equal to the expected data, a chi-square goodness of fit test on the data was conducted. The data for the last five candidates on table VIII were grouped together to ensure that all data groups have an expected value of at least 5, a prerequisite of the chi-square goodness of fit test. The hypothesis to be tested is that there is no significant difference between the simulated failure distribution and the expected failure distribution, at the 0.05 level of significance. The chi-square statistic for these two distributions is calculated as follows:

$$\chi^2 = \sum_{i=1}^{k} \frac{(F_o - F_e)^2}{F_e}$$

where F_o is the observed frequency

and F_e is the expected frequency

Using this formula, χ^2 was found to be equal to 30.186. Since this is less than 48.6, the table value of $\chi^2_{.05}$ for 34 degrees of freedom (the number of groups minus one), the hypothesis that there is no significant difference between the distributions cannot be rejected at the 0.05 level of significance. It can be concluded that the simulated failures do provide a "good fit" to the expected failures.

Validation

In order to validate the model, the mission success rate generated by the simulation was compared to the mission success rate experienced by the KC-135 aircraft fleet for the six month period that was used to determine the input MTBF's. Since the real world data is accumulated from many different types of missions, there is the possibility that the failure of a "critical" piece of equipment may not contribute to an actual abort. An example of this situation is reflected by the fact that during 114,350 hours of actual flying, there were 238 reported engine failures but only 132 aircraft aborts attributed to engine failures. This can probably be explained by the fact that if the engine failure occurred during the portion of the mission, when the aircraft was returning to base, the mission would be considered complete and an abort would not be logged. To compensate for this situation, the number of failures, rather than the number of aborts, for the following "critical" aircraft equipment candidates was used:

Critical System	Aborts/Failures
1. Engines..................	132/238
2. Water Injection..........	57/198
3. Engine Controls..........	4/ 32
4. Flight Controls..........	17/ 27
5. Hydraulic System.........	14/ 20

The sum of the above failures plus all other aborts attributed to the candidates considered in the baseline configuration is 736. Thus, the average for the entire KC-135 fleet, with a six month total of 114,350 flying hours, is 155.37 hours per abort or critical failure.

During the 45,350 simulated flying hours accumulated during the 3000 Monte Carlo trial run, there were 143 aircraft aborts and 184 mission aborts for a total of 337 aborts. This equates to 139.54 hours per abort.

Of the 6000 aircraft launched during the simulation, 5663 completed the mission, yielding a mission success rate of 94.4 percent. Since the six month fleet data was compiled from sorties of varying duration, it is difficult to determine the actual mission success rate for the KC-135 fleet for that period. If one assumes that the average flight time for the fleet is equal to that in the simulation, 7.63 hours, then the approximate number of aircraft launched would be 14,987. Of these, 14,251 did not abort or experience a critical failure, yielding a mission success rate of 95.1 percent. If this assumption of average flight time is valid, then the simulated success rate of 94.4 percent is very close to actual success rate. The average time between aborts of 139.5 and 155.4 for the simulation and real world, respectively, also suggest that the AEP does reasonably model the real world and can be considered a valid model.

Analysis

Now that the AEP has been shown to simulate real world data, it must be determined if it can be used to assess alternate avionic systems that are being considered in the KC-135 Avionics Modernization Program. To accomplish this, the mission success rates and navigation error for the baseline, single INS, and dual INS configurations were compared. These three configurations were first used in the Loring Tanker Task Force mission profile. Next, these same configurations were used in the Mildenhall EWO mission profile to determine the impact of a different mission on the results of the simulation. Table IX shows the data that was collected from these six runs.

This data shows a marked decrease in navigation error is obtained when a single INS is added to the baseline configuration, while the addition of a second INS and the removal of the navigator causes virtually no change in the navigation error or mission success rate. This can be seen in both mission profiles. The EWO mission success rate was higher than the peacetime rate because of the lower abort criteria that was used for the EWO profile.

One of the real advantages of simulation is the ability to readily perform a sensitivity analysis. Sensitivity analysis consists of systematically varying of the input parameters and/or input variables over some range of interest and observing the effect upon the models response. Such experimentation can help tremendously in building confidence in the results of the model (Ref 4:235).

The correlation time constant input parameter, used in the model to compute navigation error, was not well understood at the onset of this study. All data sources contacted were unable to define this parameter or provide this data for the KC-135 aircraft. Since this parameter

TABLE IX

NAVIGATION ERRORS AND MISSION SUCCESS RATES

DATA	NAVIGATION EQUIPMENT		
Loring TTF Mission	BASELINE	SINGLE INS	DUAL INS
Mean Navigation Error at Rendezvous Point (NM)	9.68	1.86	1.82
Mean Navigation Error After Last Refueling (NM)	14.33	2.76	2.71
Mission Success Rate (%)	93.7	93.8	93.9
Mildenhall EWO Mission Mean Navigation Error at Rendezvous Point (NM)	17.31	3.47	3.36
Mean Navigation Error After Refueling (NM)	19.58	3.92	4.02
Mission Success Rate (%)	98.95	98.95	98.85

had to be estimated, sensitivity analysis was performed to determine the impact of a possible inaccurate estimate. The default value for this parameter in the AEP model is infinity. Initial trial runs of the model using this value were made while debugging the program input data. After the debugging process was completed, the values for the correlation time constants were set to equal to zero (minutes). Several runs were made using this value before the values were changed to one minute for the INS navigation (mode 1) and ten minutes for all other navigation modes. Table X shows the results of these runs. The data shows that there is little change in the navigation error when the correlation time constant is changed from 0 to 1-10 minutes. There is a more significant change in the navigation error when the default value of infinity is used. The values of 1 and 10 minutes will be left in the model unless a reason for change can be seen.

TABLE X

NAVIGATION ERROR VERSUS CORRELATION TIME CONSTANT

DATA	Correlation Time Constant (min)		
Baseline	0	1-10	∞
Mean Navigation Error at Rendezvous Point (NM)	9.86 (5.52)	9.35 (5.65)	(4.65)
Mean Navigation Error After Refueling (NM)	14.33 (10.09)	14.25 (10.22)	(9.09)
Single INS			
Mean Navigation Error at Rendezvous Point (NM)	1.86	1.84	3.22
Mean Navigation Error After Refueling (NM)	2.76	2.76	3.66

(Note: Data in parenthesis are from flight profile 2)

IV. Summary, Conclusions, and Recommendations

Summary

The Air Force Avionics Laboratory has a computer model called the Avionics Evaluation Program that computes equipment failures, navigation error, and mission success rates for a specified type of aircraft flying a specified mission. The equipment failures are computed by making many Monte Carlo trials of a single mission using the mean time between failures for the aircraft equipment that are specified as input parameters. Based on the aircraft abort and loss criteria specified by the user, the model determines the number of aircraft and mission aborts that occur during the simulation. The ability to sample navigation error at various points in the mission, which was added during this study, allows the user to determine the navigational accuracy of various navigation systems. This study assumed that navigation and mission success were solely dependent on the KC-135 and the navigation capability and reliability of various receiver aircraft was not considered.

This research was done to determine whether the AEP could be used to model the KC-135 aircraft mission accurately. A comparison of the results of the model was made with actual field data to validate the output of the AEP. Analysis of the results showed that there is no significant difference between the model output and the field data.

The most significant result of this research was establishing a KC-135 baseline for the AEP. This study has done all of the necessary research and data collection for the KC-135 aircraft and all of this data is stored as a permanent file within the AEP. Any future KC-135 equipment tradeoff study may be accomplished with minimum time and effort. This capability should be invaluable for assessing alternate avionics equipment during the KC/C-135 Avionics Modernization Program.

Conclusions

It appears that the Avionics Evaluation Program can be used to accurately model the mission of the KC-135, a strategic aircraft, even though it was originally designed to model tactical fighter aircraft. There is also good reason to believe that the AEP can objectively assess alternate avionic system design/concepts for the KC-135 aircraft, in terms of mission success, in a realistic mission environment. This entire study was done under the assumption that the KC-135 can safely complete its tanker mission by replacing the navigator with cost effective avionics systems. While this study considered only the Delco Carousel IV INS as a replacement for the navigator, the model is capable of assessing the impact of any new avionics suite that might be considered during the KC-135 avionics modernization program. The results of this study show that the addition of a single INS to tho current aircraft configuration would allow the KC-135 to operate in the North Atlantic track system within the 10 nautical mile tolerance established by the International Civil Aeronautical Organization. It was also shown that by deleting the navigator and replacing him with a second INS, that navigational accuracies could be maintained with no significant change in the mission success rate. The impact of the new strategic doppler on the KC-135 mission was not addressed because of the lack of information available on that system. Additional equipment, deemed necessary to allow the KC-135 navigator to be replaced, will subsequently have to be put into the AEP to determine their impact on the overall mission success rate. Once all equipment changes have been specified, a decision on whether or not those systems are "cost effective" will have to be made. Although cost was intentionally deleted from this study, the AEP does have a cost accumulation subfunction that could be used at a later date to determine if the suggested changes would be cost effective.

Recommendations

This study only considered two-ship tanker cells for the simulation. The analysis might also be done using a single aircraft as well as three and four-ship cells to determine the impact of the number of aircraft per cell has on the output of the model.

As with the KC-135, there is a large scale B-52 avionics modernization program currently in progress. Since the AEP was shown to adequately model the KC-135 mission, it is suggested that the AEP be used to model the B-52 mission. The B-52 mission could be used to evaluate the survivability, target acquisition, and weapon delivery functions used in the AEP model. In many senses, the B-52 mission is very similar to the tactical fighter mission for which the AEP was designed. Since the AEP is available on the ASD computer, the Strategic Systems SPO would have easy access to the model.

There are three changes to the AEP that are recommended. First, that the random number seed used in the model be changeable to assist in the process of validating the models output. It is nice, however, to have a constant random number seed when performing sensitivity analysis with the model. Second, that the last set of output data labeled "A/C Abort Equipment Status Summary", be reformatted to provide the user with a clearer picture of the simulation. This would be especially helpful while debugging the input data and parameters. Instead of the current format, the following format is suggested. For each abort that occurs during the simulation, print a line showing the failed equipment, the time that the failure occurred, and the time of the abort as follows:

<u>A/C Abort / Equipment Failure Summary</u>

1. 51-7 @ 03+15, 62-1 @ 04+30., 23-2: Abort @06+05
2. 23-1: Abort @ 05+50, 51-7 @ 06+05, 23-4: A/C Loss @ 06+45

This type of output data would be of greater value to the user than the present format. This format would also allow the user to check at a glance that the desired abort logic was being used in the model.

Third, the current model only collects data on equipment failures for thirty minutes after an abort. For long mission profiles, this may not be sufficient since subsequent failures may occur and cause the loss of that aircraft. The model should be changed so that when an aircraft aborts, the aircraft would proceed to the takeoff base or landing base (whichever is closer) and collect equipment failure data until the aircraft is back on the ground.

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APPENDIX A

Glossary of Acronyms

GLOSSARY OF ACRONYMS

AEP	Avionics Evaluation Program
AFAL	Air Force Avionics Laboratory
AFFDL	Air Force Flight Dynamics Laboratory
AMP	Avionics Modernization Program
EWO	Emergency War Orders
FOV	Field of View
HF	High Frequency
IFF	Identify Friend or Foe
INS	Inertial Navigation System
MTBF	Mean Time Between Failure
QPA	Quantity Per Aircraft
RAF	Royal Air Force
ROC	Required Operational Capability
SAC	Strategic Air Command
TAACE	Tanker Avionics/Aircrew Complement Evaluation
TTF	Tanker Task Force
UHF	Ultra High Frequency
WUC	Work Unit Code

APPENDIX B

Aircraft Equipment Reliability Data

Aircraft Equipment Reliability Data

EQUIPMENT CURRENTLY BEING USED		MTBF(HRS)
11	AIRFRAME	
	1 KC-135/A ACFT	100000
13	LANDING GEAR	
	1 LANDING GEAR	1361
	2 EMERGENCY LANDING GEAR	100000
14	FLIGHT CONTROLS	
	1 FLIGHT CONTROLS	4235
23	PROPULSION SYSTEM	
	1 J-57 ENGINE NO.1	1920
	2 J-57 ENGINE NO.2	1920
	3 J-57 ENGINE NO.3	1920
	4 J-57 ENGINE NO.4	1920
	5 ENGINE CONTROLS	3573
	6 WATER INJECTION SYSTEM	577
41	AIR-CONDITIONING, PRESSURIZATION	
	1 ENVIRONMENTAL CONTROL	8796
42	ELECTRICAL POWER SUPPLY	
	1 ELECTRICAL SYSTEM	1545
	2 COPILOTS INSTRUMENT POWER	1167
44	LIGHTING SYSTEMS	
	1 ACFT LIGHTING	22870
45	HYDRAULIC AND PNEUMATIC POWER SUPPLY	
	1 HYDRAULIC SYSTEM	5717
46	FUEL SYSTEM	
	1 FUEL SYSTEM	8167
	2 AIR REFUELING SYSTEM	11435
51	INSTRUMENTS	
	1 PILOTS FLIGHT DIRECTOR	2334
	2 COPILOTS FLIGHT DIRECTOR	2334
	3 PILOTS INSTRUMENTS	2765
	4 COPILOTS INSTRUMENTS	2858
	5 PILOTS ALTIMETER	1167
	6 COPILOTS ALTIMETER	1167
	7 PERISCOPIC SEXTANT (2)	101
	8 ENGINE INSTRUMENTS	1700
	9 FUEL QUANTITY SYSTEM	2118
	10 REFUELING INSTRUMENTS	22870

Aircraft Equipment Reliability Data

		MTBF(HRS)
52	AUTOPILOT	
	1 N-1 COMPASS SYSTEM	2432
	2 J-4 COMPASS SYSTEM	1633
62	VHF COMMUNICATIONS	
	1 HF RADIO ARC-58	163
63	UHF COMMUNICATIONS	
	1 UHF RADIO NO.1 ARC-34	370
	2 UHF RADIO NO.2 ARC-34	370
65	IFF	
	1 IFF/SIF SYSTEM	8168
71	RADIO NAVIGATION	
	1 VOR/LOC RECEIVER	811
	2 TACAN RECEIVER	3811
72	RADAR NAVIGATION	
	1 SEARCH RADAR APN-59	1203
	2 BEACON RADAR APN-69	1230
	3 DOPPLER RADAR SYSTEM	1844
	4 NAV.COMPUTER ASN-7	1330
	5 CAROUSEL IV INS (NO. 1)	4000
	6 CAROUSEL IV INS (NO. 2)	4000

APPENDIX C

Aircraft Performance Data

Aircraft Performance Data

Name = KC-135

Weight = 105,000 lb

Reference Area = 2433 sq. ft.

Drag Brake Coefficient = 0.0

Maximum Normal Acceleration = 2.0 g's

Maximum Lift Coefficient (CL) Versus Mach No.

Mach	.00	.20	.40	.50	.55	.60	.65	.70	.75	.80	.85	.90
CL	1.10	1.03	.96	.89	.85	.83	.84	.83	.775	.67	.46	.165

Maximum Mach No. Versus Altitude

Alt (ft)	0	5000	10,000	20,000	29,000	40,000
Mach	.535	.600	.660	.785	.900	.900

Angle of Attack (Alpha) Versus CL

CL	.44	.64	.65	1.19	1.27	1.36	1.43	1.49	1.54	1.58
Alpha	0	2.4	5.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0

CL	1.60
Alpha	16.0

Available Thrust (lbs) Versus Altitude and Mach No.

Mach Number	Altitude (feet) 0	5000	10000	20000	30000	40000
.00	39800	35680	31860	24192	18088	11632
.10	39800	35680	31860	24192	18088	11632
.20	39860	35680	31860	24192	18088	11632
.30	39800	35680	31860	24192	18088	11632
.40	38960	35248	31640	24484	18244	11720
.50	38480	34948	31392	24654	18564	11952
.60	38320	34648	31336	24852	18968	12264
.70	37120	34616	31336	25144	19480	12656
.80	34200	34616	31392	25540	20016	13156
.90	31280	34616	13584	25900	20612	13668

Drag Coefficients Versus Lift Coefficient and Mach No.

Lift Coefficient

Mach Number	.10	.15	.20	.25	.30	.40	.50	.60	.70	.80	1.00
.10	.017	.017	.017	.017	.018	.022	.027	.033	.041	.059	.072
.70	.017	.017	.017	.017	.018	.022	.027	.033	.041	.050	.072
.78	.017	.017	.017	.017	.019	.023	.028	.037	.046	.058	.085
.80	.017	.017	.017	.018	.019	.024	.030	.039	.051	.061	.090
.82	.017	.017	.017	.018	.020	.025	.033	.043	.056	.077	.122
.84	.017	.017	.018	.019	.021	.028	.038	.052	.065	.088	.135
.86	.019	.019	.020	.021	.024	.034	.048	.067	.094	.130	.215
.88	.022	.023	.024	.026	.030	.044	.070	.130	.210	.350	.500
.90	.028	.029	.030	.033	.039	.061	.120	.200	.300	.400	.600

Fuel Flow (lb/hr) Versus Altitude and Mach No.

Mach Number	Altitude (feet) 0	5000	10000	20000	30000	40000
.00	35183	31113	27463	20442	15013	9596
.10	35183	31113	27463	20442	15013	9596
.20	35183	31113	27463	20442	15013	9596
.30	35183	31113	27463	20442	15013	9596
.40	35921	32005	28349	21497	15726	9974
.50	36710	32746	29006	22285	16466	10482
.60	37707	33435	29801	23038	17318	11087
.70	37528	34374	30553	24264	18175	11795
.80	35534	35031	31204	25106	18995	12406
.90	33501	35793	31995	25978	19829	13094

APPENDIX D

Subfunction Mode/State Relationships

Reference List of Equipment Designation Numbers

EQUIPMENT CURRENTLY BEING USED

11 AIRFRAME
  1 KC-135/A ACFT
  2 EWO WEIGHT AIRFRAME
13 LANDING GEAR
  1 LANDING GEAR
  2 EMERGENCY LANDING GEAR
14 FLIGHT CONTROLS
  1 FLIGHT CONTROLS
23 PROPULSION SYSTEM
  1 J-57 ENGINE NO.1
  2 J-57 ENGINE NO.2
  3 J-57 ENGINE NO.3
  4 J-57 ENGINE NO.4
  5 ENGINE CONTROLS
  6 WATER INJECTION SYSTEM
41 AIR-CONDITIONING, PRESSURIZATION AND
  1 ENVIRONMENTAL CONTROL
42 ELECTRICAL POWER SUPPLY
  1 ELECTRICAL SYSTEM
  2 COPILOTS INSTRUMENT POWER
44 LIGHTING SYSTEMS
  1 ACFT LIGHTING
45 HYDRAULIC AND PNEUMATIC POWER SUPPLY
  1 HYDRAULIC SYSTEM
46 FUEL SYSTEM
  1 FUEL SYSTEM
  2 AIR REFUELING SYSTEM
51 INSTRUMENTS
  1 PILOTS FLIGHT DIRECTOR
  2 COPILOTS FLIGHT DIRECTOR
  3 PILOTS INSTRUMENTS
  4 COPILOTS INSTRUMENTS
  5 PILOTS ALTIMETER
  6 COPILOTS ALTIMETER
  7 PERISCOPIC SEXTANT
  8 ENGINE INSTRUMENTS
  9 FUEL QUANTITY SYSTEM
  10 REFUELING INSTRUMENTS
52 AUTOPILOT
  1 N-1 COMPASS SYSTEM
  2 J-4 COMPASS SYSTEM
62 VHF COMMUNICATIONS
  1 HF RADIO ARC-58
63 UHF COMMUNICATIONS
  1 UHF RADIO NO.1 ARC-34
  2 UHF RADIO NO.2 ARC-34
65 IFF
  1 IFF/SIF SYSTEM
71 RADIO NAVIGATION
  1 VOR/LOC RECEIVER
  2 TACAN RECEIVER
72 RADAR NAVIGATION
  1 SEARCH RADAR APN-59
  2 BEACON RADAR APN-69
  3 DOPPLER RADAR SYSTEM
  4 NAV.COMPUTER ASN-7
  5 CAROUSEL IV INS 1
  6 CAROUSEL IV INS 2

Subfunction Mode/State Relationships

Used for Baseline Configuration

```
STATES FOR  3.3 REFUELING
ID      EQUIPMENT
 1     23- 1   23- 2   23- 3   23- 4   45- 1   46- 2   51-10

 ID     MODE                        REQUIREMENTS
  1     AIR REFUELING             A1B1


STATES FOR  4.1 LAUNCH
ID      EQUIPMENT
 1     11- 1   13- 1   14- 1   23- 1   23- 2   23- 3   23- 4
       23- 5   23- 6   42- 1   42- 2   44- 1   45- 1   46- 1
       51- 1   51- 2   51- 3   51- 4   51- 5   51- 6   51- 7
       51- 8   51- 9   51-10   52- 1   52- 2   62- 1   63- 1
       63- 2   65- 1   71- 1   71- 2   72- 1   72- 2   72- 3
       72- 4
 ID     MODE                        REQUIREMENTS
  1     LAUNCH                    A1B1


STATES FOR  4.2 INFLIGHT AIRCRAFT ABORT
ID      EQUIPMENT
 1     11- 1   14- 1   23- 1   23- 2   23- 3   23- 4   23- 5
       42- 1   45- 1
 ID     MODE                        REQUIREMENTS
  1     ABORT 1                   A1B1
```

Baseline Configuration (continued)

```
STATES FOR  4.3 MISSION ABORT
ID      EQUIPMENT
 ID     MODE                          REQUIREMENTS
  1     MSN ABORT 1


STATES FOR  4.4 AIRCRAFT LOSS
ID      EQUIPMENT
 1     11- 1    23- 1    23- 2
 2     11- 1    23- 1    23- 3
 3     11- 1    23- 1    23- 4
 4     11- 1    23- 2    23- 3
 5     11- 1    23- 2    23- 4
 6     11- 1    23- 3    23- 4
 ID     MODE                          REQUIREMENTS
  1     AIRCRAFT LOSS


STATES FOR  4.5 LANDING
ID      EQUIPMENT
 1     11- 1    13- 2    23- 1
 2     11- 1    13- 2    23- 2
 3     11- 1    13- 2    23- 3
 4     11- 1    13- 2    23- 4
 ID     MODE                          REQUIREMENTS
  1     LANDING
```

Baseline Configuration (continued)

```
STATES FOR  7.1 RADIO-AIDED NAVIGATION
ID      EQUIPMENT
 1     71- 2
 2     71- 1
 ID     MODE                      REQUIREMENTS
  1     TACAN FIX ERROR        A1    B1
  2     VOR FIX ERROR          A2    B2
```

```
STATES FOR  7.2 SELF-CONTAINED NAVIGATION
ID      EQUIPMENT
 1     51- 7   52- 1   72- 3   72- 4
 2     51- 7   52- 2   72- 3   72- 4
 3     52- 1   72- 3
 4     52- 2   72- 3
 5     51- 7   52- 1
 6     51- 7   52- 2
 7     52- 1
 8     52- 2
 ID     MODE                      REQUIREMENTS
  2     DR - AIDED BY DPLR &   A1    A2    B1    B2
  3     DR - AIDED BY DOPPLE   A3    A4    B3    B4
  4     DR - AIDED BY LOP'S    A5    A6    B5    B6
  5     DR - MANUAL            A7    A8    B7    B8
```

Baseline Configuration (continued)

```
STATES FOR  9.1 INTERFLIGHT COMMUNICATIONS
ID      EQUIPMENT
 1     63- 1    63- 2
 2     63- 1
 3     63- 2
 ID     MODE                     REQUIREMENTS
  1     UHF INTERFLIGHT COMM   A1B1
  2     UHF INTERFLIGHT/ONE    A1B2    A1B3    A2B1    A3B1    A2B2    A2B3
                               A3B2    A3B3
STATES FOR  9.2 EXTERNAL COMMUNICATIONS
ID      EQUIPMENT
 1     62- 1
 ID     MODE                     REQUIREMENTS
  1     HF EXTERNAL COMM       A1    B1


STATES FOR 11.1 DISPLAY ACQUISITION
ID      EQUIPMENT
 1     72- 1    72- 2
 2     72- 1
 ID     MODE                     REQUIREMENTS
  1     RADAR/BEACON ACQUISI   A1    B1
  2     RADAR/WEATHER ACQUIS   A2    B2


STATES FOR 11.2 VISUAL ACQUISITION
ID      EQUIPMENT
 ID     MODE                     REQUIREMENTS
  1     VISUAL RENDEZVOUS
```

Subfunction Mode/State Relationships

(That Were Changed for Single and Dual INS Configurations)

SINGLE INS WITH NAVIGATOR

STATES FOR 7.2 SELF-CONTAINED NAVIGATION

ID	EQUIPMENT			
1	52- 1	72- 5		
2	52- 2	72- 5		
3	51- 7	52- 1	72- 3	72- 4
4	51- 7	52- 2	72- 3	72- 4
5	52- 1	72- 3		
6	52- 2	72- 3		
7	51- 7	52- 1		
8	51- 7	52- 2		
9	52- 1			
10	52- 2			

ID	MODE	REQUIREMENTS			
1	INS NAVIGATION	A1	B1	A2	B2
2	DR - AIDED BY DPLR &	A3	A4	B3	B4
3	DR - AIDED BY DOPPLE	A5	A6	B5	B6
4	DR - AIDED BY LOP'S	A7	A8	B7	B8
5	DR - MANUAL	A9	A10	B9	B10

DUAL INS - NO NAVIGATOR

STATES FOR 7.2 SELF-CONTAINED NAVIGATION

ID	EQUIPMENT	
1	52- 1	72- 5
2	52- 2	72- 5
3	52- 1	72- 6
4	52- 2	72- 6

ID	MODE	REQUIREMENTS							
1	INS NAVIGATION	A1	A2	A3	A4	B1	B2	B3	B4

Subfunction Mode/State Relationships

(That Were Changed for EWO Profiles)

```
EWO MISSION

STATES FOR  3.3 REFUELING
ID     EQUIPMENT
 1    23- 2   23- 3   23- 4   45- 1   46- 2
 2    23- 1   23- 3   23- 4   45- 1   46- 2
 3    23- 1   23- 2   23- 4   45- 1   46- 2
 4    23- 1   23- 2   23- 3   45- 1   46- 2
 ID    MODE                    REQUIREMENTS
  2    B-52 AIR REFUELING    A1B1   A1B2   A1B3   A1B4   A2B1   A2B2
                             A2B3   A2B4   A3B1   A3B2   A3B3   A3B4
                             A4B1   A4B2   A4B3   A4B4

STATES FOR  4.1 LAUNCH
ID     EQUIPMENT
 1    14- 1   23- 1   23- 2   23- 3   23- 4   23- 5   23- 6
      45- 1   46- 1   51- 8
 ID    MODE                    REQUIREMENTS
  1    LAUNCH                A1B1

STATES FOR  4.2 INFLIGHT AIRCRAFT ABORT
ID     EQUIPMENT
 1    14- 1   23- 1   23- 2   23- 3   23- 5   45- 1
 2    14- 1   23- 1   23- 3   23- 4   23- 5   45- 1
 3    14- 1   23- 2   23- 3   23- 4   23- 5   45- 1
 4    14- 1   23- 1   23- 2   23- 4   23- 5   45- 1
 ID    MODE                    REQUIREMENTS
  1    ABORT 1               A1B1   A1B2   A1B3   A1B4   A2B1   A2B2
                             A2B3   A2B4   A3B1   A3B2   A3B3   A3B4
                             A4B1   A4B2   A4B3   A4B4
```

EWO Profile Data (continued)

```
STATES FOR  4.3 MISSION ABORT
ID      EQUIPMENT
 ID     MODE                          REQUIREMENTS
  1     MSN ABORT 1
AEPDECK COMMAND
--  SHOW.SUB.4-4
STATES FOR  4.4 AIRCRAFT LOSS
ID      EQUIPMENT
 1     23- 1   23- 2
 2     23- 1   23- 3
 3     23- 1   23- 4
 4     23- 2   23- 3
 5     23- 2   23- 4
 6     23- 3   23- 4
 ID     MODE                          REQUIREMENTS
  1     AIRCRAFT LOSS


STATES FOR  4.5 LANDING
ID      EQUIPMENT
 1     13- 2   23- 1
 2     13- 2   23- 2
 3     13- 2   23- 3
 4     13- 2   23- 4
 ID     MODE                          REQUIREMENTS
  1     LANDING
```

VITA

Joel R. Jerabek was born on 28 August 1948 in Rochester, Minnesota. He graduated from John Marshall High School in Rochester, Minnesota in 1966 and attended Mankato State College in Mankato, Minnesota, from which he received the degree of Bachelor of Science in Mathematics in 1970. Upon graduation, he received his commission through Officers Training School. After attending Undergraduate Pilot Training at Columbus AFB, Mississippi, he served as a KC-135 pilot in the 922nd Air Refueling Squadron, Wright-Patterson AFB, Ohio, and in the 905th Air Refueling Squadron, Grand Forks AFB, North Dakota. He also served as a Wing Command Post Controller for the 319th Bomb Wing, Grand Forks AFB, ND. He was assigned to the Air Force Institute of Technology, Wright-Patterson AFB, Ohio in August 1977 to earn the degree of Master of Science in Operations Research with a specialty area of Strategic and Tactical Sciences.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The KC/C-135 Avionics Modernization Program is currently tasked with determining the feasibility of replacing the KC/C-135 navigator with cost effective avionics systems. The Avionics Evaluation Program (AEP) is a computer model that has been built to evaluate the mission impact caused by alternate avionics hardware configurations. Although the AEP was designed to model tactical aircraft missions, this thesis examines whether it could be applied to the strategic mission of

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the KC-135.

Aircraft performance data, hardware reliability data, and abort logic criteria were input into the model. A baseline simulation was conducted using the current KC-135 configuration. Two additional configurations, single inertial navigation systems (INS) with a navigator and dual INS without a navigator, were selected and simulations conducted. These simulations were conducted with both peacetime and wartime mission scenarios.

An analysis of the AEP output data revealed that the addition of a single INS produced a significant improvement in navigational accuracy and that by replacing the navigator with a second INS, navigational accuracy could be maintained without a change in the mission success rate. The baseline established by this thesis is available for future use in evaluating other avionics configurations for the KC-135.